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Morphological Characterization and Evaluation of Sorghum [*Sorghum bicolor* (L.) Moench] Landraces in Benishangul Gumuz, North-western Ethiopia

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ABSTRACT

Although sorghum is an important cereal crop in Benishangul Gumuz, few studies have been undertaken on existing diversity. Hence, the objective of this study was to characterize sorghum landraces collected from five districts of north western BGRS. Twenty-five sorghum genotypes including the local check (Emohay) were tested in RCBD with three replications during the 20011/2012 rainy seasons at Pawe to assess the presence and degree of variability for desired morphological traits in sorghum landraces. Plots with two rows per plot each 5 m long with spacing of 0.75 m between rows, 0.15 m between plants and 1.5 m between blocks (a plot area of 7.5 m^2) was used. Analysis of variance revealed significant differences among entries for most quantitative characters. Eleven landraces gave better grain yield between 41.38 to 48.9 q/ha indicating the possibility of identifying superior genotype to be selected among the landraces. Genotype 021pw-2010 was the highest yielded (48.9 q/ha) landrace. The lowest GCV and PCV were obtained for days to maturity while the highest PCV and GCV were obtained for plant height. Higher ratios of the phenotypic variance to genotypic variance were recorded for days to flowering, days to maturity, leaf length, leaf width, single leaf area, number of leaves, plant height, head length, head width, head weight and grain yield indicating that the traits will be highly influenced by the environment. Broad sense heritability estimates for the traits ranged from 45.1% (for head weight) to 99.8% (for single leaf area). Grain yield showed higher significant positive genetic correlation with days to maturity, head weight, head width and head length, and a negative significant correlation with single leaf area and number of leaves at phenotypic level. The high performing accessions of the landraces screened in this study should further be evaluated under a wide range of environments to find widely adapting landraces. The variability observed in the study could be given emphasis while planning a breeding strategy for increased grain yield. Collection, conservation and utilization of available materials across BGRS must be given attention.

1. INTRODUCTION

Sorghum is a leading cereal crop in the arid and semi-arid regions of the world, ranking fifth in importance among the world's grain crops after wheat, maize, rice and barley. It is a C_4 crop particularly adapted to the drought prone areas with hot, semi-arid tropical environments, receiving an annual rainfall of 400-600 mm which is too dry for other cereals like maize (Vittal *et al*., 2010). In Ethiopia, it is an important food crop and is widely grown in the high land, low land and semi-arid region of the country (Adugna, 2007). It is a traditional food widely grown in Ethiopia, in 13 of the 18 major agro ecological zones, grown on over 1.3 million hectares. It is predominantly used for food, 80 percent of it for injera (flat pancake like traditional bread) making following tef [*Eragrostis tef* (Zucc.) Trotter] (Yilma, 1991).

As one of the leading traditional food cereals in Ethiopia, in terms of both total production and area, major research efforts have been directed towards the improvement and stabilization of sorghum yields. At a national level, sorghum improvement involves the manipulation of indigenous and introduced germplasm to develop adapted types for the various ecological zones (Yilma, 1991). Ethiopia has a diverse wealth of sorghum germplasm adapted to a range of altitudes and rainfall conditions. Because of its global socio-economic importance, there is a constant need for the improvement of sorghum (Vittal *et al*., 2010). There is high genetic diversity in sorghum in Ethiopia with several pockets of geographical isolation. The current number of indigenous sorghum germplasm contained in the gene bank stands at about 6 thousand and represents a wide array of diversity in the major sorghum growing areas of Ethiopia. This could serve as valuable genetic base for breeding and improvement of the crop in the country and the world at large (Wasihun, 2007).

Highly desirable genetic characteristics were identified in some of the Ethiopian sorghum germplasm and were utilized in breeding programs extensively elsewhere in the world. The wealth of genetic variability in the Ethiopian germplasm has been and will continue to be useful sources of economically important traits (Melaku, 1988). Important traits reported from Ethiopian sorghum include cold tolerance, drought resistance, resistance to sorghum shoot fly, disease and pest resistance, grain quality and resistance to grain mould, high sugar content in the stalks, and high lysine and protein content (IBC, 2008). Systematic characterizations and evaluation of plant genetic resources are prerequisites for the efficient use of material through conventional methods. Morphological, biochemical and molecular procedures are currently being employed in evaluating plant genetic resources (Mahmoods *et al.*, 2008). It was found earlier that genetic improvement of crops for quantitative traits requires reliable estimates of genetic variability, heritability and genetic advancement in respect to the breeding material that is presently at hand in order to plan an efficient breeding program. And the information on variability and heritability of characters is essential for identifying characters amenable to genetic improvement through selection (Govindaraj *et al.*, 2010).

Although the diversity of sorghum is high in Ethiopia, the extent and distribution of genetic variability of the crop in different ecologies has not been properly studied (Melakhail, 1975). One of the potential areas is the north western Benishangul Gumuz regional state of Ethiopia. This zone lies within the area of sorghum domestication and as such is rich in genetic diversity of cultivated sorghum and its wild forms. Because of its unique agro ecological setting of warm humid climate, the area is rich in special class of sorghum germplasm adapted to this condition. With the intention of getting varieties, which fit to the area, a collection of landraces was made from the four districts of Metekel zone. This study was conducted in order to measure the level of variation in morphological characteristics of the sorghum germplasm collections of this area.

The objectives of the study were to:

1. Determine the extent and degree of variability in morpho-agronomic characters of the sorghum collections
2. Evaluate yield and yield associated traits among the sorghum collections
3. Identify the sorghum accessions that are superior in desirable agronomic characters for use in the breeding programs.

2. MATERIALS AND METHODS

2.1. Description of the Experimental site

The experiment was conducted at PARC in Pawe district, Metekel Zone, north western part of Benishangul Gumuz Regional State, Ethiopia, from mid-2011 to early 2012 main cropping rainy season. The research center is located at about 580 km north west of Addis Ababa and 230 km from Bahir dar at $36^{o}25$`E longitude, $11^{o}12$'N latitude and at an altitude of 1150 meters above sea level. The area is characterized by hot humid conditions with means maximum and minimum temperatures of 32^{o}c and 16^{o}c respectively. The annual rainfall ranges from 1500-1800 mm with five and half months' duration. The total rainfall during the growing season of sorghum is about 1659 mm.

The soil type is Haplic Altisols, very deep (>150 cm) and clay in texture. The P^{H} of the soil ranges from 5.5 to 6.9 and subsurface soils have higher P^{H} values than surface soils. The organic carbon (0.2 to 2.8 %) and total nitrogen (0.02 to 0.19 %) contents of the soil decrease with soil depth. The cation exchange capacity ranges from 20 to 51cmolc/kg.

2.2. Experimental Materials

Twenty-five accessions and one standard check (Table 1) were included in this study though accession 032pw-2010 did not emerge in. The accessions were received from PARC. The local check variety is a released commercial cultivar recommended for high and intermediate altitude zones in the country.

2.3. Experimental Design and Procedures

The experimental design was RCBD with three replications. Each genotype was planted in a plot size of 7.5 m^2 (2 rows, each 5 m long, with a spacing of 0.75 m between rows and 0.15 m between plants). The spacing between blocks was 1.5 m. The total net area requirement of the experiment was 729 m^2. During planting the seeds were drilled in rows and at about 20 days after planting thinned out to 0.15m distances. DAP (100 kg/ha) and Urea (50 kg/ha) fertilizers were applied at planting and at knee height, respectively.

2.4. Data Collected

Measurements and observations were recorded following the IBPGR and ICRISAT (1993) descriptor list. Qualitative traits were scored based on arbitrary scales found in the sorghum descriptors list as reference for the observations. All quantitative data were measured by taking the mean value of five plants, which were tagged randomly before the time of data collection.

2.4.1. Data collected on plant bases

a) Numbers of leaves per plant - leaves were counted from the base to the flag leaf after the time of blooming.
b) Leaf length (cm) - the distance from the collar to the leaf tip of the third leaf from the top was measured in cm.
c) Leaf width (cm) - width of the third leaf from the top at its widest part was measured.
d) Single leaf area (cm^2) - was calculated using the formula KxLxW, where K is the “adjustment factor” 0.747, L is length and W is the width (Stickler and Wearden, 1961).
e) Plant height (cm) – measured from the base of the stalk at ground level to the tip of the head.
f) Head length (cm) - measured from the base of the panicle to the tip of the panicle.
g) Head width (cm) - the diameter of the head at its widest part
h) Head weight (g) - the mean value of 5 plants head weight was measured.

2.4.1. Data collected on plot bases

a. Days to emergence: The number of days from sowing to 50% emergence of the plants.
b. Days to flowering: The number of days from planting to when 50% of the plants in plot reached 50% flowering.
c. Days to maturity: The number of days from planting to the date where 95% of the plant matured on which seeds on the lower part of panicle formed black layer.
d. Head shape: Scored on a 1-3 scale.
e. Head compactness: scored on a 1-12 scale.
f. Inflorescence exertion: This was scored on a 1-4 scale.
g. Grain covering with glumes: Scored by visual observations of the grain on the whole plants from the plot
h. Grain color: It was scored based on visual observations as white, brown and red.
i. Grain yield (g): Weight of dried grain harvested from the two rows of the plot

2.5. Statistical Analysis

Before analysis of variation, the overall data set was divided into two groups. One group contained quantitative data and the other group contained qualitative data, which were coded by numbers(Table 2). For quantitative data, mean value was used for all characters but for the coded data with variation within one accession, a decision was made to use dominant character and only one code was used per accession. After verification of the data subset, frequencies of occurrence of each qualitative character were calculated by hand through percentage comparison method. Eleven recorded quantitative data were subjected to statistical analysis using NCSS, 2004, SAS statistical computer software with version 9.2 (SAS institute, 2008) and GenRes statistical computer software with version 3.11 (Pascal institute, 1994). Statistical measure of variability, such as genotypic and phenotypic coefficient of variation, broad sense heritability, genetic advance and genetic advance as percent of the mean, phenotypic correlation coefficient, path analysis and cluster analysis were performed using the above appropriate statistical computer software programs.

2.5.1. Analysis of variance

Analysis of variance (ANOVA) was performed (Table 3) for each measured quantitative trait in RCBD ANOVA (Gomez and Gomez, 1984; Rangswamy, 1995) in order to compare the relative importance of main model terms: replication(r), genotype (G) and error (e). Analysis of variance (ANOVA) was performed on eleven quantitative traits to explore the level of variation among the twenty-five populations of sorghum using NCSS, 2004 computer statistical program.

The RCBD ANOVA was computed using the mathematical model:

$$Y_{ij} = \mu + r_j + g_i + e_{ij}$$

Where: Y_{ij} = the observation of the i^{th} genotype in the j^{th} replication, r_j =the effect of the j^{th} replication and g_i

= the effect of the i[th] genotype, e_{ij}= experimental error effect.

2.5.2. Estimation of Genetic Parameters

The genetic parameters were estimated using SAS statistical computer software with version 9.2 (SAS institute, 2008).

A. Estimation of phenotypic and genotypic variances

The phenotypic and genotypic variances were estimated from the expected mean squares using the random model where the expected mean squares considered. The mean squares equated to their expectations for the estimation of variance components. Genotypic variance $(\delta^2{}_g)$ and phenotypic variance $(\delta^2{}_p)$ were estimated according to Falconer (1981) as: $(\delta^2{}_g) = \frac{MSg - MSe}{r}$, Where, $\delta^2{}_g$ is genotypic variance, MSg is genotypic mean square, MSe= error mean squares, *r* is the number of replications.

Environmental variance on genotype mean basis $(\delta^2 e) = \frac{MSe}{r}$, and Phenotypic variance $(\delta^2{}_p)$ = $(\delta^2{}_g)$ + $(\delta^2 e)$ = $\frac{MSg}{r}$, Where, $\delta^2{}_g$ is phenotypic variance. Variability was estimated using range, standard error, phenotypic and genotypic variances, and phenotypic and genotypic coefficient of variation. The phenotypic and genotypic coefficients of variation calculated according to the Burton (1952) method as:

PCV = $\sqrt{\delta^2{}_p}$ / $(\bar{Y}\ldots)\ x100$, Where $\bar{Y}$ is mean value of trait Y.

$$GCV = \sqrt{\delta^2{}_g}\ /\ (\bar{Y}\ldots)\ x100$$

B. Estimation of heritability in broad sense (H)

Heritability in broad sense (H) for all characters was computed using the formula given by Falconer (1981). Broad sense heritability (H) expressed as a percentage of the ratio of the genotypic variance $(\delta^2{}_g)$ to the phenotypic variance $\delta^2{}_p$ and was estimated on genotype mean base as described by Allard (1960).

Heritability $(H) = \frac{\delta^2{}_g}{\delta^2{}_p} \times 100$, where: H is heritability in broad sense, $(\delta^2{}_g)$ is Genotypic Variance, and $\delta^2{}_p$ is phenotypic variance.

C. Estimation of genotypic advance

Genotypic advance in absolute unit (GA) and as percent of the mean (GAM), assumed selection of superior 5% of the genotypes was estimated in accordance with the methods illustrated by Johnson *et al*. (1955) as:

GA=K $\delta^2 p\ H$, where: K is the standardized selection differential of 5% selection intensity. (K = 2.063), $\delta^2 p$ is phenotypic standard deviation on mean basis, H is heritability in broad sense. Genetic advance as percent of the mean was calculated to compare the extent of predicted advance of different traits under selection, using the formula: $GAM = \frac{GA}{\bar{x}} x100$, Where: $\bar{x}$ is mean of the population where selection employed.

2.5.3. Association of Characters

Correlation and path analysis between days to 50% flowering, days to maturity, number of leaves per plant, single leaf area, leaf length, leaf width, plant height, head length, head width, head weight and grain yield of 25 sorghum accessions were studied using SAS computer software with version 9.2 and GenRes computer software with version 3.11 computer software programs, respectively.

A. Estimation of phenotypic and genotypic correlation coefficients

Covariance analysis followed the same fashion as that of analysis of variance, and the mean cross products were equated with their expectations to solve the covariance component as:

Genotypic covariance $(\delta^2 g_{xy}) = \frac{MSCPg_{xy} - MSCPe_{xy}}{r}$

Phenotypic covariance $(\delta^2 Pxy) = \frac{\delta^2 g_{xy} + \delta^2 e_{xy}}{r}$

Phenotypic correlation, the observable correlation between two variables, which includes both genotypic and environmental components between two variables were estimated using the formula suggested by Miller *et al.* (1958) as indicated on the next page.

$$rp_{xy} = \frac{\delta^2 p_{xy}}{\sqrt{(\delta^2 p_x)(\delta^2 y)}}$$

$$rg_{xy} = \frac{\delta^2 g_{xy}}{\sqrt{(\delta^2 g_x)(\delta^2 y)}}$$

Where, rp_{xy} is phenotypic correlation coefficient and rg_{xy} is genotypic correlation coefficient between character x and y; $\delta^2 pxy$ and $\delta^2 gxy$ are phenotypic *covariance and genotypic covariance between character x and y respectively.*

Phenotypic ($\delta^2 p_{xy}$) and genotypic ($\delta^2 p_{xy}$) covariance was computed from the table of covariance analysis in a manner similar to that of the analysis of variance (Table 4).

B. Path coefficient analysis

Path coefficient analysis was analyzed using the formula suggested by Dewey and Lu (1959) to assess the direct and indirect effect of yield components on seed yield based on the following relationship with GenRes statistical computer software with version 3.11(Pascal institute, 1994).

$r_{ij} = p_{ij} + \sum r_{ik} p_{kj}$, Where: r_{ij} is mutual association between the independent character (i) and dependent character, grain yield (j) measured by the correlation coefficient, p_{ij} is component of direct effects of the independent character (i) on the dependent variable (j); as measured by the path coefficients, $\sum r_{ik} p_{kj}$ is the summation of components of indirect effect of a given independent trait (i) on the dependent variable (j) via all other independent traits (k). The contribution of the remaining unknown factor measured as residual factor (R^2) was calculated using the formula (Dewey and Lu, 1959) as:

$$U = \sqrt{1-R^2},$$

Where $R^2 = \sum r_{ik} p_{kj}$, U=the residual (unexplained variation of the dependent variable that is not accounted for by path coefficients). In this study, grain yield was considered as the dependent trait and all other ten quantitative characters were taken as independent traits.

2.5.4. Cluster Analysis of Genotypes

Mahalanobis's generalized distance (D^2) statistics was used for assessing the divergence between genotypes based on the number of traits that were measured using NCSS, 2004 computer statistical program. The generalized distance between any two populations defined as:

$$D^2 ij = (\bar{x}i - \bar{x}j)\, S^{-1}\, (\bar{x}i - \bar{x}j),$$

Where, $D^2 ij$ = the distance between any two groups i and j, $\bar{x}i$ and $\bar{x}j$ = are the vector mean of the traits for the i^{th} and j^{th} groups respectively, and S^{-1} is the inverse of the pooled covariance matrix.

3. RESULTS AND DISCUSSIONS

Morphological variation was recorded among the 25 germplasm of *sorghum bicolor* collected from different areas of north western Benishangul Gumuz Regional State, Ethiopia. The 5 qualitative and 11 quantitative characters varied among the 25 sorghum germplasm.

3.1. Qualitative Traits in the Landraces

Variability was observed in five traits including head shape and compactness, inflorescence exertion, grain covering with glumes and grain colour.

3.1.1. Head shape and compactness

The landraces were characterised by straight head (87.5%), semi-curved head (4.2%) and curved head (8.3%). The variety that was included as a standard check was of the straight-headed type. Some sorghum landraces, which were collected from North Shewa and South Wollo, had Straight head (Abdi *et al*., 2002). Variations in head shape and compactness have also been reported from landraces of South Wollo (Solomon and Lemlem, 2003). Durrishahwar *et al*. (2012) also observed variation for head shape in Pakistan.

The landraces also showed variation on head compactness as loosely headed (58.3%), semi-compact headed (20.8%) and compact headed (20.9 %). The reason for the observed high percentage of loosely headed landraces than the compact headed and semi compact headed landraces seems that there was targeted selection of materials for grain mould resistance in the areas where the accessions were collected among the local farmers. Stemler *et al*. (1977), Rao and Mengesha (1981) and Thakur *et al.* (2008) explained that the loosely headed sorghums are more resistant to grain mould (a fungal disease) than compact headed sorghums. Because the loosely headed sorghums have an adaptive trait (open panicle) which facilitates quick drying of the panicle in areas of high rainfall and humidity, thereby minimizing grain weathering due to fungal diseases such as grain mould. Amsalu and Endashaw (1998) also reported a variation on head compactness.

Contradictory to this study, Abdi *et al*. (2002) reported 33% of 34 accessions were compact headed which are dominant in North Shewa and South Welo. Amsalu and Endashaw (1998) reported loosely headed types with dropping branches occur abundantly in relatively cool and wet regions of Ethiopia like Wollega, Illubabur, Shewa and Sidamo where susceptibility to grain mould is high due to the increase in humidity.

3.1.2. Inflorescence exertion

The inflorescence exertion, measured as the amount of exposed peduncle from the flag leaf to the base of the panicle was recorded to be slightly exerted (64%), exerted (20%), and well exerted with long peduncle (8%) and peduncle curved (8%). Habindavyi (2009) reported 48% well exerted, 36% exerted and 17 % less exerted landraces from 50 sorghum landraces of Burundi. A case study by Solomon and Lemlem (2003) indicates that there is a greater variability of sorghum landraces of north-eastern Ethiopia on their inflorescence exertion. Abdi *et al.* (2002) also reported variability among 34 sorghum accessions in their inflorescence exertion (59% of the accessions with well exerted inflorescence).

3.1.3. Grain color

The genotypes produced white (48%), red (32%) and brown (20%) coloured seeds. This seems that the result of conscious artificial selection chosen genotypes with white colour and discriminates genotypes with brown and red colour seeds. In the same way Durrishahwar *et al*. (2012) reported white seeded sorghum as the most frequent landraces in Pakistan. Habindavyi (2009) also reported brown sorghum grains as the second dominant (25%) grain colour when dealing on morphological characterization of 52 sorghum landraces in Burundi. The author reported red grains as the most dominant (52%) and white coloured grains as the least dominant (23%). Amsalu and Endashaw (1998) discussed that white and brown seeds were the most frequent seed types of sorghum collected from different areas of Ethiopia and Eritrea. However, they concluded that red sorghum seeds are more frequent than brown seeds of sorghum. Solomon and Lemlem (2003) also reported variability in grain colour of sorghum accessions in their case study folk classification of sorghum in north-eastern Ethiopia. Dogget (1982) stated white colour seeded sorghums are known for their food quality despite their vulnerability to grain mould. The white grain sorghum lacks polyphenolic compounds that serve to protect the sorghum grain from pre-harvest germination in humid regions in intermediate and highland areas, while red and brown colour, seeded types are rich in polyphenolic compounds (Ashante, 1995).

The observed frequencies of the different colour categories in this study could be associated with the utilization and disease tolerance aspects of the crop. Sorghum is the staple food in the whole collection areas where white colour grain types make better quality ‘injera’ and porridge than the other two grain types. The brown and red colour grain types are mainly used for making a local homemade alcoholic drink called ‘Tella’. Besides, the white seeded sorghums have better market price than the other two sorghum types and that is why these white seeded sorghums have larger land covers than brown and red seeded types of sorghum.

3.1.4. Grain covering with glumes

Sixty percent of the landraces had 25% covered grains, 36% of the landraces had grains that are half covered, and 4% of the landraces had grains that are fully covered with glumes. This seems to have favoured grains either half covered or 25% covered with the glumes. This seems to be an adaptive feature that facilitates quick drying that minimizes grain mould. Habindavyi (2009) reported the most dominant 25% covered grains (47%), second dominant (35%) half covered grains and the least dominant (2%) sorghums with fully covered grains. Elangovan *et al*. (2007) reported a glumes covering variation among sorghum accession. Thakur *et al.* (2008) also reported a variation of sorghum landraces in their grain covering and concluded that greater glumes coverage of grains appeared to be more closely associated with grain mould resistance than other traits.

3.2. Variability of Quantitative Traits

The significant mean square values obtained from the analysis of variance suggests that differences existed among the sorghum germplasm for most characters, indicating that they are highly variable (Table 6). The results indicated that there is a significant difference ($P<0.05$) among genotypes for the traits such as days to 50% flowering, days to maturity, number of leaves per plant, plant height, head weight and grain yield. There is also a significant difference ($p<0.01$) for the traits of leaf length, single leaf area, and head length. But the genotypes did not significantly vary for the traits of head width and leaf width. The significant difference obtained indicates the presence of genetic variability for those traits with a significant mean square value (Table 6). A higher variation for a character in the breeding materials correlates with a greater ability for its improvement through selection (Mahdieh *et al*., 2012). The CV is useful when comparing the experimental variation differences in experiments that have variables measured in different units and large coefficients of variation (>30%) are often associated with increased experimental variability (Taylor *et al*., 1999). Therefore, grain yield (CV=19.08) has the greater ability to be improved through selection and days to 50% flowering (C.V =2.65) correlated with a least ability for its improvement among the 11 quantitative traits. Non-significant mean square values observed for some characters showed that the genotypes are genetically similar concerning these characters. Selecting for these characters will therefore show no impact on genetic improvement (Bello *et al*., 2007). Therefore, leaf width and head width will not have impact on genetic improvement of the sorghum accessions.

Previous studies on collection of sorghum landraces indicate significant variation for many of the traits like head length and head width, days to 95% maturity (Habindavyi, 2009). Negash (2003) also reported that days to 95% maturity, leaf width, leaf length, leaf area, plant height and grain yield have a significant difference between sorghum landraces collection from Western region of Ethiopia. Doggett (1988) and House (1985) showed the presence of substantial amount of variability among sorghum genotypes for different agronomic traits like field emergence, days to maturity, and time to flowering. In contrast to the study of Negash (2003) variability is not obtained in days to emergence in the present study. Wasihun (2007) obtained a result similar to this finding except for days to 50% flowering, which has a significant difference in this study.

3.2.1. Ranges and means

A wide range of values in quantitative traits has been observed (Table 7). The sorghum germplasms have a broad range of variability in grain yield per plot (4538 g to 2174 g/plot or 60 to 28.9 q/ha). The studied genotypes also showed range of variability in their days to 50% flowering (41-128 days), days to 95% maturity (130-170 days), leaf length (71.8-112.8 cm), number of leaves (458-895) and leaf width (8-17 cm) and in single leaf area (7.07-9.6 cm^2).

According to Amsalu (2000), mature sorghum leaves may reach a width of 6.5 to 13.46 cm at the widest point and the number of leaves on the main stem may vary from 6.96 to 20.63. In a related study by Geremew (1993), leaf length was reported to a range of 45.22–126.37 cm. The variability in plant height among genotypes was high and ranged between 423-203 cm. Variability in plant height of Ethiopian sorghum ranged from 72 to 615 cm has been reported by Berhane and Yilma (1978). Variation in head length, head weight and head width was also observed in this study with a range of variability from 43.2-19.00 cm, 120.8-47.00 g and 12-5 cm respectively. Almost similar result was obtained by Melakhail and Rao (1982) and Wasihun (2007). Therefore, the existence of wider morphological diversity among the sorghum landrace collections implies the potential to improve the crop and the need to conserve these resources.

Mean grain yield of the accessions was 2988.63 g/plot that is 39.84 q/ha with the variation ranging 60 q/ha to 29 q/ha. Genotype 021PW-2010 was the highest yielder landrace (48.9 q/ha) which is almost less by 11 quintals when compared to the check variety (Emohay having a potential to give 60 q/ha). Eleven landraces gave between 40.2 - 40 q/ha grain yields. These landraces were 044pw-2010, 035pw-2010, 001pw-2010, 021pw-2010, 050pw-2010, 056pw-2010, 049pw-2010, 055-2010, 041pw-2010 and 023pw-2010. The mean values of the quantitative characteristics studied are shown in Table 5. The presence of genotypes with good yield performance is an indication for the possibility of developing high yielding varieties from the available materials for Pawe and similar areas.

3.2.2. Variability estimate for the quantitative traits

Variability parameters for different morpho-physiological characters were assessed to determine patterns of genetic variation among the genotypes. Variability present within the sorghum germplasm estimated from the range of values for phenotypic and genotypic coefficients of variation, heritability and genetic advance of each character. Generally, the GCV are lower in magnitude than the PCV. Similar results were obtained by Bello *et al.* (2007) while studying genetic variability in cultivated sorghum. Abdi *et al*. (2002) and Addisu (2011) also reported a variability result on the quantitative characteristics of sorghum germplasm.

A. Phenotypic and genotypic variation among the genotypes

Across the 11 characters, the genotypic and phenotypic coefficient of variation (GCV & PCV) ranged from 5.9% to 6.1% for days to 95% maturity and 15.8% to 16.2% for plant height, respectively, as indicated on table 7. Negash (2003) and Wasihun (2007) obtained the lowest PCV and GCV for days to 95% maturity. Addisu (2011) also reported the lowest genotypic and phenotypic coefficients of variation for 95% days to maturity (8.22% and 8.75% respectively) but in contrast, he recorded the highest GCV and PCV for days to 50%flowering. Godbharle *et al.* (2010) reported high genotypic and phenotypic coefficient of variation for pant height, head width and head length, and low GCV and PCV for days to flowering (5.86% and 6.85% respectively). If The PCV was higher than the GCV for the traits, the traits will be highly influenced by environment and the reverse is true (Godbharle *et al*., 2010). Therefore, in the present study the high ratios of the phenotypic variance to genotypic variance for days to flowering, days to maturity, leaf length, leaf width, single leaf area, number of leaves per plant, plant height, head length, head width, head weight and grain yield indicated that the traits will be highly influenced by environment.

B. Heritability estimates in broad sense

Although the genotypic coefficient of variation revealed the extent of genetic variability present in the landraces for various traits, it does not provide full scope to assess the heritable variation. Heritable variation is useful for permanent genetic improvement (Jalal *et al.*, 2011). The most important function of heritability in the genetic study of quantitative characters is its predictive role to indicate heritability of the phenotypic value as a guide to breeding value (Falconer and Mackay, 1961).

High heritability estimates for single leaf area (99.62%), days to 50% flowering (97.8%), plant height (95.7%), number of leaves per plant (94.3%), leaf length (93.9%), and days to 95%maturity (93.5%) and leaf width (70%) were obtained (Table 7), indicating a high response to selection. In a similar fashion, a high heritability for head length (96%), days to 50% flowering (95%), and days to 95% maturity (99%) was reported by Bello *et al*. (2007). Mahajan *et al.* (2011) also reported a high heritability in plant height (92.12%), head width (92.97%) and days to 50% maturity (89.57%). A low heritability for head width (59.7%), head weight (45.1%) and grain yield (51.6%) recorded in the present study. Therefore, the masking effect of the environment is high on these traits and selection for the traits will not be easy for the plant breeder. Deepalakshmi and Ganesamurthy (2007) reported a high heritability in days to 50% flowering (94.6%), 95% days to maturity (90.80%), and in head weight (96.90%). Negash (2003) reported high heritability for days to 50% flowering (77%), plant height (78.50%) and head length (84.80%). Wasihun (2007) also reported high heritability for days to 50% flowering (97%), days to 95% maturity (99%), leaf length (75%), single leaf area (75%), and plant height (94%) and grain yield (94%). A lowest heritability in head weight (45.10%) and a highest heritability in single leaf area (99.62%) were observed. Bellow *et al.* (2007) reported a lowest heritability in grain yield (10%) but Deepalakshmi and Ganesamurthy (2007) reported the highest heritability in grain yield (98.7%).

In general, heritability was high for most quantitative characters studied suggesting that selection for those traits would be effective. Nevertheless, it should be noted that this is broad sense heritability and hence it is not absolute indicator of efficiency (Singh, 1999). According to Singh (1999), if heritability of a character is very high, say 80% or more, selection for that character is easy, but the masking effect of the environment is high on traits with low heritability (less than 40%). Therefore, selection for single leaf area (99.62%), days to 50% flowering (97.8%), plant height (95.7%), number of leaves per plant (94.3%), leaf length (93.9%) and 95% days to maturity (93.5%) will be easy for plant breeders.

C. Estimates of genetic advance

In this study estimate of genetic advance (GA) ranged from 1.39 cm for leaf width to 9.65q/ha for grain yield (Table 7). That is the resultant population obtained after crossing the best 5% of the materials will produce a new population whose leaf width is increased by 1.39 cm and whose yield is better than the older population by 9.65 q/ha. Low predicted response to selection was observed for leaf length (16.83 cm), head weight (13.6 cm), head length (9.64 cm), days to 50% flowering (5.78 days), number of leaves per plant (4.20), and days to 95% maturity (2.06), head width (1.77 cm) and for leaf width (1.39 cm). A higher value of GA was observed for single leaf area (220.96 cm^2), plant height (116.35 cm) and grain yield (9.65 q/ha).

Wasihun (2007) reported high values of GA for grain yield (880.33 g) and single leaf area (152.25 cm^2). Negash (2003) also reported high values of GA for plant height (82.2 cm) and single leaf area (91.3 cm^2). He also reported GA less than 10 for number of leaves per plant, head length, head width and head weight. Godbharle *et al*. (2000) reported a high value of GA in kharif sorghum. Deepalakshmi and Ganesamurthy (2007) also reported high GA for plant height (31.45 cm) and head length (29.12 cm). The genotypic coefficient of variation along with heritability estimate provides reliable estimates of the amount of genetic advance expected through phenotypic selection (Burton, 1952).

GAM was moderate for all characters except days to 50% flowering, which recorded its low estimate (5.1%). Maximum GAM recorded for plant height (33%) followed by head length (32.9%) and number of leaves per plant (30%). Similarly, Wasihun (2007) reported low GAM in days to 50% flowering (0.15%) among the sorghum collections in western Ethiopia. He reported low to high GAM for days to 95% maturity (0.11%), leaf width (4.12%), leaf length (0.46%), single leaf area (24.94%), number of leaves per plant (3.31%), plant height (0.2%), head width (26.63%), head length (2.23%), head weight (42.17%), and Grain yield (58.52%). Deepalakshmi and Ganesamurthy (2007) also reported high GAM for plant height, days to 50% flowering, number of leaves per plant, leaf length and head weight.

The estimate of GA helps in understanding the type of gene action involved in expressing various polygenic characters when considered jointly with heritability. High values of GA are indicative of additive gene action where as low values are indicative of non-additive gene action (Singh and Narayanan, 1993). Thus, days to 50% flowering estimated high heritability (97.8%) and low genetic advance as percent of the mean (5.78%) indicating that this character is affected by environment and is controlled by non-additive gene action and it will have poor response for selection (Godbharle *et al*., 2010). Days to 95% maturity (H=93.5%; GAM=12.7%), leaf width (H=70%; GAM=19.7%), leaf length (H=93.9%; GAM =16.9%), head length (H=92.8; GAM=32.9%), head width (H=45.1%; GAM=16.6%), and grain yield (H=51.6%; GAM=24.33%), which expressed high heritability with moderate GAM, appeared less affected by environmental fluctuations and governed by both additive and non-additive gene action, suggesting the possibility of improving these characters through simple selection methods. Deepalakshmi and Ganesamurthy (2007) also confirmed this statement. High heritability coupled with moderate GAM for head length reported by Godbharle *et al*. (2010).

3.3. Genotypic and Phenotypic Correlation Coefficients of the Traits

The association of all morphological traits was estimated by genotypic and phenotypic correlation coefficients (Table 8). The higher magnitude of genotypic correlation coefficients (r_g) than phenotypic correlation coefficients (r_p) recorded in a correlation of days to 50% flowering with leaf width, head length and head weight, days to 95% maturity with head length, head weight and grain yield, leaf length with leaf width, head length, head weight, number of leaves per plant with leaf width, and head weight, leaf width with plant height, head weight, and head length, single leaf area with head length, and grain yield with head length, head width, and head weight. Godbharle *et al.* (2010) stated that traits with higher genotypic correlation have inherent association. Therefore, the above quantitative traits in this study with higher genotypic but lower phenotypic correlation coefficient have inherent association.

There was positive and significant genotypic correlation of grain yield with days to 95% maturity (r_g = 0.69**), head length (r_g =0.74*), head width (r_g = 0.33**) and head weight (r_g = 0.63**) indicating that increase in grain yield is because of increase in one or more of the above characters. Similar results were reported by Bohra *et al*. (1986) for head length, Deepalakshmi and Ganesamurthy (2007) for number of leaves per plant and head weight, and Ezeaku and Mohamed (2006) for head weight. Grain yield is significantly and negatively correlated with single leaf area (r_p = -0.25*) and number of leaves per plant (r_p = -0.32**) at phenotypic level (Table 8). Geremew (1993), Negash (2003) and Wasihun (2007) reported that grain yield is positively and significantly correlated with head weight. Deepalakshmi and Ganesamurthy (2007) reported that days to 90% maturity and head weight are positively and significantly correlated with grain yield and a negative significant correlation between number of leaves per plant and grain yield. Elangovan *et al.* (2007) reported a positive and significant correlation of head width with grain yield at genotypic level. In agreement with this study, Ezeaku and Mohamed (2006) also reported a positive correlation between plant height and head length; head length and head weight; head length and grain yield but in contrast, a negative correlation between plant height and head weight; plant height and grain yield; and head weight and grain yield.

3.4. Path Coefficient Analysis

The estimates of correlations alone may be often misleading due to mutual cancellation of component traits. The path coefficient analysis initially suggested by Wright (1921) and described by Dewey and Lu (1959) allows partitioning of correlation coefficients into direct and indirect contributions (effects) of various traits towards the dependent variable and thus helps in assessing the cause-effect relationship as well as effective selection. Hence, this study aimed to analyse and determine the traits having greater inter-relationship with grain yield utilizing the correlation and path analysis.

The results of path analysis (Table 9) revealed that days to 50% flowering (0.38), days to 95% maturity (0.45), leaf length (0.14) and head length (0.28) showed positive direct effect with grain yield. Leaf width (-0.58), single leaf area per plant (-0.18), number of leaves per plant (-0.17), plant height (-0.76), head width (-0.15) and head weight (-0.19) showed a negative direct effect on grain yield per plot. This shows that direct selection of days to 50% flowering, days to 95% maturity, leaf length and head length will be effective in improving sorghum grain yield but increasing leaf width, single leaf area per plant, number of leaves per plant, plant height, head width and head weight through selection may not necessarily lead to proportionate increase in grain yield. Similarly, Mahajan *et al*. (2011) reported positive direct effect of head length (0.4036) on grain yield and contradicted to this finding a negative direct effect on days to 50% flowering and days to 95% maturity and a positive direct effect on head width (0.8432) and plant height (0.4329).

Deepalakshmi and Ganesamurthy (2007) reported that days to 50 % flowering (0.129), days to 95% maturity (0.491), head length (0.438), leaf length (0.070) have a positive direct effect on sorghum grain yield. Moreover, plant height (-0.149) has a negative direct effect on grain yield. Contradictory to this finding he reported a positive direct effect of number of leaves per plant (0.820) and head weight (0.854) on grain yield. Days to maturity (0.45) showed the highest positive direct effect while leaf length (0.14) showed the least positive direct effect and plant height (-0.79) showed the highest negative direct effect while head width (-0.15) showed the least negative direct effect on grain yield per plot. Ezeaku and Mohamed (2006) reported a highest positive direct effect of head weight (0.97) and the lowest positive direct effect of head length (0.03) on grain yield.

According to the study of Mahajan *et al*. (2011) days to 50% flowering has the highest negative direct effect (-0.1570) and days to 95% maturity have the least negative direct effect (-0.0935) on grain yield. Mahajan *et al.* (2011) stated that head width, head length and plant height, which have positive direct effect on grain yield, had greater importance in improving grain yield. Thus, it revealed from the present study that the traits like days to 50% flowering, days to 95% maturity, leaf length and head length had greater importance. Hence, due consideration should be given to these characters while planning a breeding strategy for increased grain yield in sorghum. The residual effect (0.63) indicates that characters, which are included in the path analysis, explained almost 99.36% of the total variation in seed yield.

3.5. Cluster Analysis

Eleven quantitative characters were used as input for cluster analysis. Hierarchical method of cluster analysis was performed using NCSS, 2004 computer software program based on a dissimilarity matrix and a considerable variability observed between the clusters. However, the landraces have been collected in different areas, some are similar and sharing cluster (grouped in a cluster) and some others originally collected from similar area are placed in different clusters. Thus, even if the landraces are originally collected from different area, they are sharing some morphological characteristics. The 25 sorghum germplasm grouped in 5 clusters (Fig. 1). The number of landraces per cluster ranged from one in cluster I to eight in cluster III (Table 10).

Cluster I consisted of only the local check (Emohay) which is characterized by high yield, short leaves, early maturity and shorter height which makes it easy for harvesting. Cluster II contains 4 genotypes having early flowering and maturity date. The shortest genotype is included in this cluster and this makes the genotype most suitable for harvesting but it is characterized on average, by lower grain yield. But among the landraces, the highest grain yielder germplasm (021pw-2010 which gave 3565 g/plot or 48.9q/ha) was found in this cluster. Cluster III consisted of eight genotypes that have late maturity date (162.26 days) relative to the standard check and cluster II and IV member sorghum genotypes, intermediate plant height and higher grain yield among the tested sorghum landraces (3037.8 g/plot or 41.67 q/ha). They have longer leaves (102.97 cm).

Cluster IV and V are composed of intermediately flowering (118.16-118.71 days) and maturing (162.21-162.93 days) accessions. Both clusters are composed of six genotypes, which contain high yielder genotypes. Cluster V consisted of taller accessions (394.95 cm average plant height), which will make them difficult for harvesting. The tallest landrace (412.3 cm) 026pw-2010 was also found in this cluster. Diversity for sorghum accessions was also reported earlier (Abdi *et al*., 2002, Wasihun, 2007, Abe, 2010 and Durrishahwar *et al*., 2012).

For all the clusters, the distance between clusters centred (D^2) detected (11). All the clusters were different from one another indicating that the sorghum landraces under the study varied morphologically. The cluster mean values of the 11 quantitative characters were computed to compare the clustered accessions of sorghum as indicated on table 12.

Table 1. List of sorghum landraces and the standard check included in the study

No	Accession No	Local Name	Collection area	Altitude	Seed Color
1	033pw-2010	Bobea	Village 49	894	Red
2	037pw-2010	Bobea	Village 1	1044	Brown
3	035pw-2010	Bobea	Village 1	1044	White
4	043pw-2010	Bobea	G/beless	980	Brown
5	044pw-2010	Bobea	Village 1	1044	White
6	045pw-2010	Bobea	Village 1	1044	Red
7	026pw-2010	Auto	Icide	915	Brown
8	030pw-2010	Auto	Icide	915	Brown
9	047pw-2010	Bobea	Baruda	-	red
10	001pw-2010	Mehareb	Almehal	680	White
11	003pw-2010	Tirequash	Almehal	685	White
12	012pw-2010	Gergesa	Banguze	808	White
13	020pw-2010	Drisisa	Icica	890	White
14	021pw-2010	Jarsisa	Icide	890	White
15	050pw-2010	Bobea	Dibate	-	White
16	056pw-2010	Bobea	Dibate	-	White
17	005pw-2010	Bobea	Village 23	-	Red
18	049pw-2010	Bobea	Baruda	-	Red
19	055pw-2010	Bobea	Zeghe	-	White
20	031pw-2010	Bobea	Village 1	1044	White
21	032pw-2010	Bobea	Village 49	894	White
22	027pw-2010	Auto	Icide	915	Red
23	041pw-2010	Bobea	Village 1	1044	White
24	042pw-2010	Bobea	Village 1	1044	Red
25	023pw-2010		Dechagree	862	Brown
26	Emohay	Check	-	-	Brown

Table 2. Qualitative characters scored following the sorghum descriptor lists (IPGRI/ICRISAT, 1993)

	Characters/Codes/ Description
1.	Grain color. Codes: 1. White; 2. Brown; 3. Red
2.	Head shape. Codes: 1. straight; 2. Curved; 3. Semi curved
3.	Head compactness. Codes: 3. Loose: 7. Semi compact 9. Compact
4.	Inflorescence exertion. Codes: 1. Slightly exerted; 2. Exerted; 3. Well exerted; 4. Peduncle curved
5.	Grain covering with glumes. Codes: 1. 25% grain covered: 3. 50% grain covered: 5. 75% grain covered 7. Grain fully covered: and 9. glumes longer than grain

Table 3. Analysis of variance for 11 traits for the 25 sorghum germplasm

Source of variation	df	Mean square	Expected mean
Replications	(r-1)	MSr	δ^2e-gδ^2r
Genotypes	(g-1)	MSg	δ^2e-rδ^2g
Error	(r-1) (g-1)	MSe	δ^2e
Total	rg-1		

df = degrees of freedom, r = number of replication, g = number of genotypes, MSr = mean square of replications, MSg = mean square of genotypes, MSe = mean square of error.

Table 4. Analysis of covariance

Source of variation	*df*	Mean square	Expected mean
Replication	r-1	MSCPrxy	
Genotype	g-1	MSCPgxy	δ^2exy+rδ^2gxy
Error	(r-1) (g-1)	MSCPexy	δ^2exy

Where: df-degrees of freedom, r-number of replications, g-number of genotypes, MSCPr$_{xy}$-mean sum of cross products of replication for traits x and y, MSCPg$_{xy}$-sum of cross products of genotype for traits x and y, MSCPe$_{xy}$-sum of cross products of environment for traits x and y, $\delta^2 e_{xy}$-environmental covariance between traits x and y, $\delta^2 g_{xy}$-genotype covariance of traits x and y.

Table 5. Genotype Mean summary of 11 quantitative characters and values obtained for five qualitative characters of 25 sorghum genotypes grown in 2011/2012 rainy season in Pawe district

No.	Accessions	DTE	DTF	DTM	LFW	LFL	SLA	NOL	PH	HL	HW	HWt	GRY	IEX	HS	HC	GLC	GRC
1	033pw-2010	7	120	165	7.6	99.5	754.1	15	385	27.7	9.3	93	3329.3	1	3	3	3	3
2	037pw-2010	7	112	160	7.4	104.5	758.1	14	379.7	33.6	10.5	91.1	2174	1	3	3	1	2
3	035pw-2010	7	94	139.7	6.1	86.7	535.8	11	244.7	28.6	7.2	88.9	3017	1	3	3	3	1
4	043pw-2010	7	117.3	161.7	7.1	100.4	703.5	14	346.7	28.5	9.3	76.4	2641.7	1	3	3	1	2
5	044pw-2010	7	120.3	161.7	7.4	105.5	781.7	15	309.3	24.1	9.3	73.1	3152.3	4	1	9	1	1
6	045pw-2010	7	122	160	5.6	101.7	593.2	15	372.6	27.4	7.1	80.8	2643.3	1	3	7	3	3
7	026pw-2010	7	117.7	163	8.2	101.5	741.8	15	412.3	32.2	9.6	86.7	2462.6	3	3	3	3	2
8	030pw-2010	7	119.3	161.3	8.1	108.1	870.3	15	404.3	30.3	7.9	79.3	2302.3	2	3	7	3	2
9	047pw-2010	7	122.7	161.3	7.9	105.9	834.4	14	354	25.2	7.5	70	2847	1	3	9	1	3
10	001pw-2010	7	91.3	138.3	6.7	89.3	607.1	11	245	24.6	6	66.9	3375.7	1	3	3	1	1
11	003pw-2010	7	90.3	137.3	7	90.3	641.9	10	236.7	30.3	6.7	89.2	2829.7	2	3	3	1	1
12	012pw-2010	7	96.7	140.3	8.4	87.9	740.7	12	284	26.8	8.3	64.5	2596	1	3	7	1	1
13	020pw-2010	7	114.7	161.7	7.7	98.4	759.7	16	365.7	28.3	7.8	80.9	2549.7	1	3	9	3	1
14	021pw-2010	7	115	163.3	6.5	107.3	706.2	14	359.3	30.2	8.1	85.1	3565	2	3	9	1	1
15	050pw-2010	7	122	165	7.4	101.1	766.1	15	386.7	40.5	9.3	98.4	3347.7	1	3	7	1	1
16	056pw-2010	7	126	161.7	7.5	111.9	832.3	15	391.3	26.7	7.9	68.7	3379.7	1	3	9	1	1
17	005pw-2010	7	122.7	161.7	7.6	97.9	745	16	391.7	24.3	7.7	76.2	2941.3	1	2	7	1	3
18	049pw-2010	7	120	163.3	6.6	108.4	652.6	15	408	33.2	7.2	94.3	3023.3	1	3	3	3	3
19	055pw-2010	7	115.7	161.7	6	99.7	604.7	14	389.7	30	8	78.1	3342.7	2	3	3	1	1
20	031pw-2010	7	119.3	163.3	6	104.1	624	15	393.7	28.3	8.3	75.7	2908.3	1	3	3	1	1
21	027pw-2010	7	121.3	163.3	7.6	102.5	781.3	13	401.7	33.3	7.3	96.7	2418.7	1	3	3	7	3
23	041pw-2010	7	120.7	165	7.4	96.5	722.4	14	308	19.4	8.1	63.2	3225.7	4	1	3	1	1
24	042pw-2010	7	112.7	161.7	6.3	99.4	629.7	15	386.7	28.7	8.7	89.8	2760	1	3	3	3	3
25	023pw-2010	7	119.3	163.3	6.3	98.4	611.7	12	404.7	32.7	7.4	90	3169	2	3	3	1	2
26	Emohay	7	88	141	6.7	75.7	528.3	8	266.7	36.1	7	92.3	4503	3	3	3	3	3

DTE-days to emergence, DTF-days to 50% flowering, DTM-days to 95% maturity, LFW-leaf width (cm), LFL-leaf length(cm), SLA-single leaf area (cm2), NOL-number of leaves per plant, PH-plant height (cm), HL-head length (cm), HW-head width (cm), HWt-head weight(g), GRY -grain yield (g/plot), IEX- inflorescence exertion, HS-head shape, GLC- glumes covering, GRC-grain color.

NB. Accession number 22 missed in all three replications and the trait DTE is not included in all analysis because it is constant for all accessions.

Table 6. Table of analysis of variance (ANOVA)

Source of variation	Mean Squares											
	df	DTF	DTM	LFW	LFL	SLA	NOL	PH	HL	HW	HWt	GRY
Replication	2	0.04	287.5	0.14	59.69	2583.82	3.09	1435.88	9.75	4.85	3.18	1272149.00
Genotype	24	399.94*	273.61*	1.79	202.99*	25411.48**	12.62*	9751.24*	60.28**	3.29	313.88*	671061.10*
Error	48	1.94	17.92	0.52	12.44	4941.29	0.74	418.65	4.38	1.34	172.35	325204.40
R^2		0.95	0.89	0.63	0.89	0.72	0.89	0.92	0.87	0.57	0.47	0.54
C.V		2.65	2.68	10.22	3.54	10.01	6.19	5.79	7.13	14.42	15.97	19.08

**, ** Significant at 0.05 and 0.01 probability level, R^2=efficiency of the model, CV= coefficient of variation, DTF =Days to 50% flowering, DTM=days to 95% maturity, LFW=leaf width, LFL=leaf length, SLA=single leaf area, NOL=number of leaves per plant, PH=Plant height, HL=head length, HW=head width, HWt=head weight, GRY =grain yield, df=degrees of freedom*

Table 7. Genetic parameters for eleven quantitative traits in sorghum genotypes

Characters	N	R	Min	Max	Mean ± SD	MSg	MSE	GV	PV	GCV	PCV	H	GA	GAM
DTF	75	41	87	128	113.64 ± 11.7	399.94	1.94	130.27	133.31	10.1	10.2	97.8	5.78	5.1
DTM	75	40	130	170	157.83 ± 10.4	273.61	17.92	85.23	91.2	5.9	6.1	93.5	2.06	12.7
LFW	75	4.8	4.8	9.6	7.07 ± 0.96	1.79	0.52	0.42	0.6	9.2	11	70	1.39	19.7
LFL	75	41	71.8	112.8	99.61 ± 8.7	202.99	12.44	63.52	67.66	8	8.3	93.9	16.83	16.9
SLA	75	437	458	895	702.31 ± 107.3	25411.48	4941.29	8453.86	8470.3	13	13.1	99.8	220.96	31.5
NOL	75	9	8	17	13.88 ± 2.2	12.62	0.74	3.96	4.24	14.4	14.8	94.3	4.20	30.3
PH	75	220	203	423	353.19 ± 58.9	9751.24	418.65	3110.86	3250.4	15.8	16.2	95.7	116.35	33
HL	75	24.2	19	43.2	29.33 ± 4.8	60.28	4.38	18.63	20.09	14.8	15.3	92.8	9.64	32.9
HW	75	7	5	12	8.04 ± 1.4	3.29	1.34	0.65	1.09	10.1	13	59.7	1.77	22.1
HWt	75	73.8	47	120.8	82.19 ± 14.6	313.88	172.35	47.18	104.63	8.4	12.5	45.1	13.6	16.6
GRY	75	2364	2174	4538	2988.6 ± 680.4	671061.1	325204.4	115285.57	223687	11.4	15.9	51.6	724.31	24.33

DTF-days to 50% flowering, DTM-days to 95% maturity, LFW-leaf width (cm), LFL-leaf length (cm), SLA-single leaf area (cm^2), NOL-number of leaves per plant, PH-plant height (cm), HL-head length(cm), HW-head width(cm), HWt-head weight (g), GRY-grain yield (g), N-number of observations, R-range, Min-minimum, Max-maximum, MSg-mean square of genotype, MSE-mean square of error, SD-standard deviation, GV-genotypic variance, PV-phenotypic variance, GCV-genotypic coefficient of variation, PCV-phenotypic coefficient of variation, H-heritability, GA-Genetic advance, GAM- genetic advance as percent of the mean

Table 8. Genotypic (above the empty diagonal) and phenotypic (below the empty diagonal) correlation between 11 the quantitative traits

Characters	DTF	DTM	LFW	LFL	SLA	NOL	PH	HL	HW	HWt	GRY
DTF		0.00	0.28	0.00	0.00	0.00	0.00	0.44*	0.01	0.99*	0.08
DTM	0.86**		0.35*	0.00	0.00	0. 00	0. 00	0. 89**	0. 00	0. 48*	**0. 69****
LFW	0.12	0.10		0.69*	0.00	0.51*	0.99**	0.52*	0.05	0.22*	0.11
LFL	0.78**	0.69**	0.04		0.00	0. 00	0. 00	0. 88*	0. 05	0. 92**	0. 01
SLA	0.50**	0.42**	0.81*	0.51**		0.00	0.00	0.47*	0.03	0.14	0.02
NOL	0.82**	0.73**	0.07	0.68**	0.39**		0.00	0.22*	0.03	0.91**	0.00
PH	0.78**	0.74**	0.00	0.68	0.32**	0.75**		0.02	0.02	0.05	0.10
HL	-0.08	0.01	0.07	0.01	-0.08	-0.14	0.25*		0.07	0.00	**0.74***
HW	0.27*	0.33**	0.22	0.22	0.25*	0.23*	0.26*	0.20		0.30**	**0.33****
HWt	0.00	0.08	-0.14	0.01	-0.17	-0.01	0.22	0.58**	0.12		**0.63****
GRY	-0.19	-0.04	-0.18	-0.28	**-0.25***	**-0.32****	-0.18	0.03	-0.11	0.05	

**-Significant at 5%, **-significant at 1% level of significance, DTF-days to 50% flowering, DTM-days to 95% maturity, LFW-leaf width, LFL-leaf length, SLA-single leaf area, NOL-number of leaves per plant, PH-plant height, HL-head length, HW-head width, HWt-head weight, GRY -grain yield*

Table 9. Estimates of direct (on diagonal) and indirect effects (off diagonal) of different characters on grain yield

Effect of Character	Via Character										
	DTF	DTM	LFW	SLA	LFL	NOL	PH	HL	HW	HWt	r_g
DTF	**0.38**	0.43	-0.23	-0.09	0.11	-0.14	0.66	0.00	-0.06	-0.01	0.38
DTM	0.36	**0.45**	-0.16	-0.09	0.11	-0.14	0.66	0.00	-0.07	-0.02	0.45
LFW	0.15	0.12	**-0.58**	-0.08	0.08	-0.08	0.21	-0.06	-0.04	0.03	-0.58
SLA	0.19	0.22	-0.27	**-0.18**	0.08	-0.09	0.31	-0.03	-0.06	0.04	-0.18
LFL	0.31	0.36	-0.33	-0.11	**0.14**	-0.13	0.56	-0.01	-0.05	0.01	0.14
NOL	0.32	0.38	-0.30	-0.10	0.11	**-0.17**	0.57	-0.05	-0.07	0.02	-0.17
PH	0.33	0.40	-0.16	-0.07	0.10	-0.12	**0.76**	0.07	-0.06	-0.05	-0.76
HL	0.00	0.01	0.12	0.02	-0.01	0.03	0.20	**0.28**	-0.02	-0.16	0.28
HW	0.17	0.23	-0.15	-0.08	0.05	-0.08	0.31	0.04	**-0.15**	-0.02	-0.15
HWt	0.01	0.05	0.09	0.04	-0.01	0.01	0.20	0.23	-0.02	**-0.19**	-0.19

Residual Effect (R) = 0.63

DTF-days to 50% flowering, DTM-days to 95% maturity, LFW-leaf width, LFL-leaf length, SLA-single leaf area, NOL-number of leaves per plant, PH-plan eight, HL-head length, HW-head width, HWt-head weight, r_g-path coefficient

Table 10. Clustering pattern of 25 sorghum genotypes

Clusters	No of genotypes	Genotypes included in the clusters
I	1	Emohay (the standard check)
II	4	012PW-2010, 001pw-2010, 003pw-2010 and 035pw-2010
III	8	041PW-2010, 021PW-2010, 056PW-2010, 047pw-2010, 005pw-2010, 020PW-2010, 044pw-2010 and 043pw-2010
IV	6	023PW-2010, 031PW-2010, 055PW-2010, 042PW-2010, 049PW-2010 and 045PW-2010
V	6	027PW-2010, 030PW-2010, 050PW-2010, 026PW-2010, 037PW-2010 and 033PW-2010

Table 11. Mahalanobis's generalized distance (D^2) statistics of the 5 clusters of sorghum

Clusters	I	II	III	IV	V
I	0	889.53	595.38	872.91	878.03
II		0	309.61	22.659	90.299
III			0	291.1	289.88
IV				0	88.46
V					0

Table 12. Cluster mean of 11 quantitative characters of sorghum germplasm

Characters	DFL	DYM	LFW	LFL	SLA	NOL	PH	HL	HW	HWt	GRY
I	88	141	6.7	75.7	528.3	8	266.7	36.1	7	92.3	4503
II	93.07	138.9	7.05	88.55	631.37	11	252.6	27.57	7.05	77.37	2954.6
III	119.92	162.26	7.38	102.97	760.65	14.75	353.25	25.83	8.21	74.2	3037.8
IV	118.16	162.21	6.13	101.95	619.31	14.33	392.56	30.05	7.78	84.78	2974.43
V	118.71	162.93	7.716	102.86	778.61	14.5	394.95	32.93	8.98	90.86	2672.43

DTF-days to 50% flowering, DTM-days to 95% maturity, LFW-leaf width (cm), LFL-leaf length (cm), SLA-single leaf area (cm^2), NOL-number of leaves per plant, PH-plant height (cm), HL-head length (cm), HW-head width (cm), HWt-head weight (g), GRY-grain yield in gram per plot

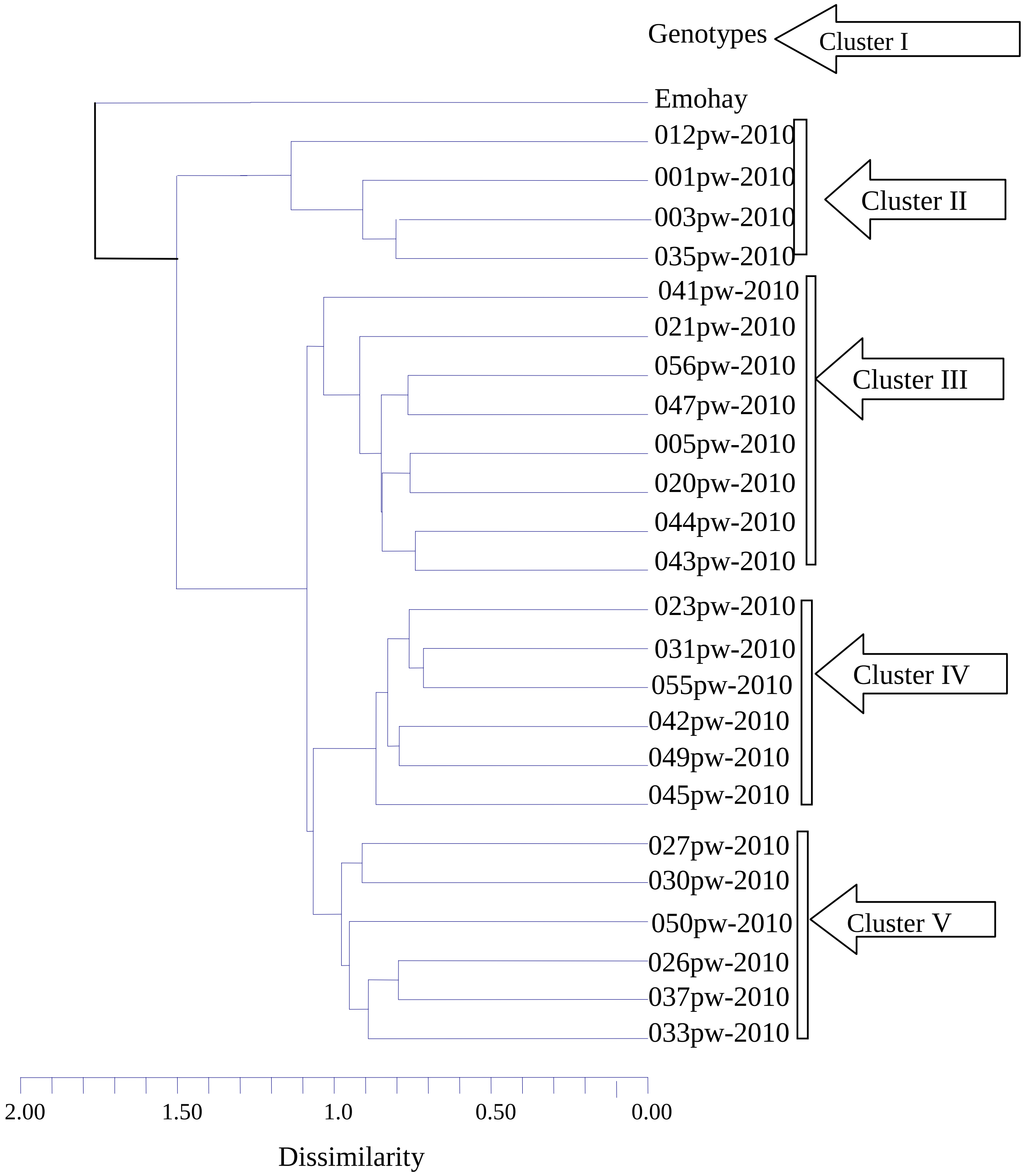

Figure 1. A dendrogram showing the clustering patterns of 25 sorghum landraces in north western BGRS, Ethiopia (key to legend: for the local name of sorghum landraces, refer to Table 1).

ABBREVIATIONS/ACRONYMS

ANOVA	Analysis of variance
CV	Coefficient of Variation
DAP	Di ammonium phosphate
df	Degrees of freedom
GA	Genetic Advance in Absolute units
GAM	Genetic Advance as percentage of the mean
GCV	Genotypic Coefficient of variation
IBC	Institute of Biodiversity Conservation
IBPGR	International Board for Plant Genetic Resources
ICRISAT	International Crop Research Institute for Semi-Arid Tropics
NCSS	Number Cruncher Statistical System
PARC	Pawe Agricultural Research Centre
PCV	Phenotypic Coefficient of Variation
PV	Phenotypic Variance
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System

4. CONCLUSION

Understanding the morphological variability correlated to the landraces distribution in the area is an important tool for efficient development of crop genetic resources. This characterization study using five qualitative and eleven quantitative characters showed a range of variation in both qualitative and quantitative characters.

Frequency distribution of the landraces into different categories of qualitative traits indicated that there is a phenotypic variability among the tested sorghum genotypes. The reason for the observed high percentage of loosely headed landraces than the compact headed landraces seems that there was targeted selection of materials for grain mould resistance in the areas where the accessions collected among the local farmers. Because the loosely headed sorghums have an adaptive trait (open panicle) which facilitates quick drying of the panicle in areas of high rainfall and humidity, thereby minimizing grain weathering due to fungal diseases such as grain mould (Stemler *et al.*, 1977; Rao *et al.*, 1981, Thakur *et al.*, 2008). The dominancy for accessions with slightly exerted inflorescence may be because of their suitability for harvesting. Among farmers and other people in the collection areas white colour grain types make better quality ‘injera’ and porridge than the other two grain types. Besides, they have better market price than the other two sorghum types and that is why these white seeded sorghums have larger land covers than brown and red seeded types of sorghum where the grains are mainly used for making a local homemade alcoholic drink called ‘Tella’.

The significant mean square values obtained from the analysis of variance suggests that differences existed between the sorghum landraces for most characters, indicating that they are highly variable. Eleven landraces gave better grain yield between 41.38 q/ha to 48.9 q/ha indicating the possibility of identifying superior genotype to be selected among the landraces for the breeding program. Genotype 021pw-2010 was the highest yielding (3565 g/plot or 48.9 q/ha) landrace, which is almost less by 11 quintals when compared to the check variety (Emohay). The presence of genotypes with good yield performance is an indication for the possibility of developing high yielding varieties from the available materials for Pawe and similar areas.

Generally, the studied genotypes showed range of variability in their days to 50% flowering, days to 95% maturity, grain yield, plant height, head length, head weight, head width, and in their leaf character (leaf length, single leaf area, number of leaves and leaf width). Therefore, morphological diversity among the sorghum landrace collections implies the potential to improve the crop and the need to conserve these resources.

The lowest genotypic and phenotypic coefficients of variation was obtained for days to 95% maturity while the highest PCV (15.8%) and GCV (16.2%) obtained for plant height. The significance differences among the sorghum landraces in the investigation indicate the presence of genetic variability in the material used and provide a good opportunity for yield improvement on sorghum accessions. High ratios of the phenotypic variance to genotypic variance for days to 95% maturity, leaf length, leaf width, single leaf area, number of leaves per plant, plant height, head length, head width, head weight and grain yield recorded indicating these traits will be highly influenced by the environment. Since most tested sorghum landraces in this research are very tall (above 3 meters), they may not be suited for harvesting.

A high heritability estimates were recorded for single leaf area (99.62%), days to 50% flowering (97.8%), plant height (95.7%), number of leaves per plant (94.3%), leaf length (93.9%), days to 95% maturity (93.5%) and leaf width (70%), indicating a high response to selection. A lower heritability for head width (59.7%), head weight (45.1%) and grain yield (51.6%) recorded. According to Singh (1999), if heritability of a character is very high, say 80% or more, selection for that character is easy, but the masking effect of the environment is high on traits with low heritability (less than 40%). Thus, selection for single leaf area, days to 50% flowering, plant height, number of leaves per plant, leaf length, and days to 95% maturity will be easy for plant breeders among the *sorghum bicolor* collections from the four districts of Benishangul Gumuz regional state. Thus, relatively rapid progress on the landraces improvement can be achieved through selection of these traits.

The estimate of genetic advance (Table 4.3) ranged from 1.39 cm (leaf width) to 724.31 g per plot (grain yield). That is the resultant population obtained after crossing the best 5% of the materials will produce a new population whose leaf width is increased by 1.39 cm, and whose yield is better than the older population by 9.65 q/ha. Days to 95% maturity, leaf width, leaf length, head length, head width, and grain yield, which expressed high heritability with moderate GAM, appeared to be less affected by environmental fluctuations and governed by both additive and non-additive gene action, suggesting the possibility of improving these characters through simple selection methods. Days to 50% flowering recorded the lowest GAM (5.1%) indicating that this character will be affected by environment and controlled by non-additive gene action.

The higher magnitude of genotypic correlation coefficients than phenotypic correlation coefficients recorded in a correlation of days to 50% flowering with leaf width, HL, and head weight; days to 95% maturity with head length, head weight and grain yield; leaf length with leaf width, head length, head weight, single leaf area, number of leaves per plant, and grain yield; number of leaves per plant with leaf width, head weight and head width, leaf width with plant height, head weight, and head length; single leaf area with head length, and grain yield with head length, head width, and head weight. Godbharle (2010) stated that traits with higher genotypic correlation coefficients have inherent association. Therefore, the above quantitative traits in this study with higher genotypic but lower phenotypic correlation coefficient have inherent association.

The results of path analysis revealed that days to 50% flowering, days to 95% maturity, leaf length and head length showed positive direct effect with grain yield while leaf width, single leaf area per plant, number of leaves per plant, plant height, head width and head weight showed a negative direct effect on grain yield per plot. Mahajan *et al*. (2011) stated that head width, head length and plant height had greater importance in improving grain yield. Thus, the present study revealed that the traits like days to 50% flowering, days to 95% maturity, leaf length and head length had greater importance. Hence, due consideration could be given to these characters while planning a breeding strategy for increased grain yield.

Most sorghum collections were in the same cluster which might be due to close proximity of collection sites and landrace exchanges could be common. Conservation and utilization of available sorghum landraces in the collection areas must be given attention. Association of phenotypic variability with genetic analysis will also help for better conclusions. The high performing accessions of sorghum landraces screened in this study should further be evaluated under a wide range of environments to find widely adapting landraces.

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